Device for Inspecting Test Objects and Use Thereof

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Ins The present invention relates to a device for the inspection of test objects ~~with the characteristics of the preamble to claim 1 as well as~~ /02 The present invention also relates to the use of the device for X-ray inspection of soldered joints on printed circuit boards and/or loaded printed board assemblies and particularly to the use of the device for completely automatic 100% X-ray inspection of soldered joints on printed circuit boards and/or loaded printed board assemblies.

B Discussion of Background Information

B A device with the ~~characteristics of the preamble to claim 1~~ above-noted features is known from European printed Patent Specification No. 0 236 001 B1. In this printed specification, systems for two-dimensional, completely automatic X-ray inspection of switch plates and board assemblies are described. Because the X-ray source and X-ray detector used have a small field of view in comparison to the horizontal extent of the area of the test object to be tested, the examination of the entire area of the test object to be examined is conducted in that the test object is moved along the X-Y plane. Thus, the known system has a multiple axis positioning system in order to receive board assemblies and to position them appropriately.

However, the known system has the following disadvantages. For one, the design of the multiple axis positioning system is very costly because, in addition to the XY axis of movement, devices must be provided for receiving and ejecting the board assemblies. Because the test object is located between the X-ray source and detector, the corresponding positioning system must also be located in the area between the X-ray source and detector. Thus, a great deal of space is needed, making the entire device voluminous. Furthermore, during the movement of the board assemblies at high speeds, the components and especially the soldered joints are stressed because of the laterally acting forces. This especially affects high attached components, but also components that, because of their structure, allow only soldered joints that are lightly wetted.

The soldered joints can be damaged by this stress. Such damage will not

necessarily become apparent immediately after the acceleration or braking process. It is just as conceivable for an imperceptible defect to appear in the soldered joints immediately after the acceleration or braking process that does not lead to a failure of the soldered joints until after a somewhat longer time has elapsed, e.g., in conjunction with temperature fluctuations or vibrations.

A further disadvantage of the known system's ~~consists of the fact~~ that it is only suitable for two-dimensional examination of test objects. It is not designed for examining individual components on the board assembly three-dimensionally.

Furthermore, the problem arises that, when board assemblies whose masses differ widely from one another are to be examined, different forces must be applied in order to move them within the predetermined cycle period. Accordingly, exact adjustment of the operating parameters is necessary for each type of board assembly.

Moreover, movement of the board assembly during the examination process causes the board assembly to vibrate up and down. As a result, therefore, waiting times for cessation of vibrations are necessary and distance measurements to the board assemblies cannot be conducted with a very great degree of accuracy. Furthermore, the vibration behavior of the board assemblies during the long illumination time of the camera (> 200 ms) leads to less than optimal picture sharpness.

The problem of a coordinated relative movement between the test object, X-ray source, and detector has furthermore been discussed in numerous patent documents that relate to improvements of tomosynthesis processes.

Tomosynthesis involves a three-dimensional X-ray imaging process in which a plurality of X-ray pictures are

taken at various relative positions of the test object and the X-ray source in order to form the cross-sectional image of a desired plane inside the three-dimensional object on the detector. In contrast to this, the problem is handled in this class-defining X-ray inspection system in a simple X-ray radiograph process without layer resolution covering the entire region of a test object to be examined with an X-ray source and a detector, each of which has a small field of view in comparison to the horizontal extent of the region of the test object to be examined.

The known tomosynthesis methods which, for example, are known from the publications of S.F. Buchele, H. Ellinger, F. Hopkins in Materials Evaluation 48, May 1990; R.J. Kruse, R.H. Bossi in Review of Progress in Quantitative Nondestructive Evaluation, Vol. 10B, 1991; D.G. Grant in IEEE Transactions on Biomedical Engineering 19, Jan. 1972; U.E. Ruttimann, X. Qi, L. Weber in Medical Physics 16(3), May/June 1989, are based on the principle of moving X-ray beam tubes and detectors while the object to be examined remains stationary. Because the highly precise positioning of X-ray beam tubes entails numerous problems relating to the degree of accuracy to be maintained and the speed of the measuring process and requires a complicated mechanical structure of the measuring device, later experiments have focused on further simplification of the measuring system, on a higher degree of accuracy, and a higher measuring speed.

Thus, German Patent Application P 42 35 183, filed by a co-applicant of the current application, describes a process for creating layer images of a three-dimensional object in which the X-ray beam source and the detector remain stationary while the object is moved.

A similar process is known from European Patent Application EP-A-0 683 389, in which a laminographic examination system with a radiation source, a sensor device, and a device for moving the test object is described. The test object is moved so that it assumes a plurality of different positions between the radiation source and the sensor device. Alternately, the radiation source and sensor device can also be moved on a

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circular path. In both cases, however, in order to inspect all the inspection areas, the test object must be moved relative to the radiation source and the sensor device.

Further concepts for solving the problems mentioned above are based on a realization of the X-ray beam tubes in which the electron beam activating the X-ray beam is deflected by deflection coils.

Thus, US Patent No. 5 097 492 describes a tomographic examination system in which the electron beam is deflected by appropriately actuated deflection coils in such a way that the X-ray beam thus produced makes a circular movement on the object to be examined in order to achieve in this manner the cross-sectional images necessary for the tomosynthesis process.

Furthermore, US Patent No. 5 259 012 describes another tomographic examination system in which, on the one hand, the electron beam makes a circular movement on the target material as a result of the coordinated deflection by means of deflection coils so that the X-ray beam thus produced makes a circular movement on the object to be examined in order to achieve in this manner the cross-section images necessary for the tomosynthesis process. On the other hand, however, another additional direct current is applied to the deflection coil in the X or Y direction so that the resulting X-ray beam is pivoted in the X-Y plane and the field of view of the X-ray focus can be moved within the X-ray source.

However, in applying the mechanism described in US Patent No. 5 259 012 to testing the entire area of a test object to be examined, the problem arises that the horizontal extent of the X-ray tube must be greater than the area of the test object to be examined. On the one hand, this leads to a very voluminous testing system and also leads to problems when test objects are used which have very differently sized areas to be examined. Furthermore, the problem arises that, because the X-ray source is actually tipped and not moved, the beam diameter of the X-ray beam varies according to whether a central section or an edge section is being tested. As a result, the accuracy of the measurement varies in the absence of electronic control of the X-ray focus.

A further disadvantage of this system ~~consists of the fact~~ is that, because the

deflection coils must be correspondingly controlled, an expensive and complicated control of the X-ray tubes is necessary.

SUMMARY OF THE INVENTION

Thus, the object of the present invention is to improve the device known from European Patent No. 0 236 001 B1 in such a way that it becomes more compact and allows a faster and truly non-destructive testing of the entire area of the test object to be examined.

According to the present invention, 03 ~~the object is attained by means of the characterizing portion of claim 1.~~ Furthermore, according to the present invention, the ~~use of~~ the device, according to the invention 04 ~~is provided in claim 10~~. ~~The preferred embodiments are the object of the subclaims.~~

The present invention is based on the surprising realization that, contrary to the widespread prevalent opinion in the current field of application, it is possible to move the X-ray beam source within the X-Y plane with a high degree of accuracy, i.e., with an accuracy of down to approximately 5 μm, and at a high speed in spite of its large mass of about 10 to 20 kg.

One reason this is possible is that a less heavy X-ray beam tube without a vacuum pump or cooling is used. Such an X-ray beam tube can be used in a satisfactory manner because, for the purposes of the current invention, as will be explained in the following, an X-ray tube with a larger focal spot diameter of greater than 10 μm, preferably up to 40 μm, can be used.

Furthermore, only the X-ray tube itself and the high voltage element containing the power supply are moved when the X-ray beam tubes are moved, while the control device for changing the working voltage or output is not moved. Nevertheless, the total mass of the mobile parts is approximately 13.5 kg.

Also, the inventors of the present invention developed a special device for moving

the X-ray beam tube and the detector horizontally in order to ensure that these components can be moved with great accuracy and at high speeds despite their large mass. This special device is based on an appropriate combination of highly precise axial components, measuring systems, and a high-performance position control system.

The following advantages can thus be achieved by the device according to the invention:

~~1.~~ The device according to the invention allows a completely non-destructive examination of the areas to be examined. More precisely, large accelerations of the board assembly in the device according to the invention are prevented so that no damage to the soldered joints occurs as a result of acceleration or braking processes of the board assemblies. Furthermore, it is not necessary to fix the board assemblies inside the mounting so that they do not move off center during acceleration/braking. The disadvantage of such a fixing is namely that the edge regions of the board assemblies, particularly the conductors located in the edge regions, can also be damaged as a result of fixing the board assemblies, for example, when the board assemblies are clamped into a mounting device. A further disadvantage is that the fixing carries the danger that the board assemblies could slip off-center in the mounting device as a result of the strong forces during acceleration or braking, which would cause damage to the conductors at the edges and force the inspection to be aborted due to a change of position.

Because the board assemblies need not absorb any acceleration or braking processes in the present invention, this danger is safely prevented.

~~2.~~ Furthermore, distance measurements at the stationary position of the board assembly to be examined can be conducted with increased accuracy, e.g., by means of a laser triangulation process.

~~3.~~ ~~Since always~~ Since components with a constant mass are moved, namely the X-ray beam source and the detector, no adaptation of the moving mechanism to the board

assembly to be examined is necessary, in contrast to the known device. Thus, increased accuracy, greater speed, and greater flexibility in the examination of board assemblies of different masses are achieved.

~~4.~~ Because of the substantially smaller areas of movement, the construction of the device according to the invention achieves a substantially smaller space requirement in comparison to conventional devices.

~~5.~~ The cycle times for the individual inspection steps do not include any inactive waiting times that would otherwise be necessary for cessation of vibrations of the moved components. Furthermore, the cycle time is ~~also~~ not impaired by the maximum acceleration or delay to be maintained.

~~6.~~ High components and those with an unfavorable center of mass do not present a problem with respect to the mechanical stability of the soldered joints.

~~6.~~ In comparison to the device known from US Patent No. 5 259 012, the range of the board assemblies to be examined is greater. For example, components with a length in the range of 70 to 500 mm, a width in the range of 50 to 500 mm, and a board assembly thickness of 0.5 to 3 mm can be examined with a device according to the invention without previously undertaking adaptations of the measuring geometry. Furthermore, inspections on an inspection surface of 500 x 500 mm are possible with the device according to the invention, where the test window inspected in each inspection has a size of approximately 6.2 cm^2.

~~7.~~ According to the present invention, a commercially available microfocus X-ray tube with a focal spot diameter of approximately 20 to 40 μm can be used. Neither a large and expensive X-ray tube as is necessary in, for example, the device described in US Patent No. 5 259 012 nor a ~~does it require require the~~ complicated control device of such an X-ray tube is required in the instant invention ~~tube~~. Furthermore, no vacuum pumps or cooling are necessary for the X-ray beam tube used for the device according to the present invention.

As will be explained further below with reference to an example, it is possible with the aid of the device according to the invention to examine individual components of a printed circuit board three-dimensionally.

So that the X-ray beam detector can be moved easily, it preferably has a low-mass. According to a preferred embodiment of the invention, the X-ray beam detector is a very high-resolution taper to which a high-resolution CCD chip is attached. For converting the received X-ray beam into visible light, the detector further includes a scintillator. According to the present invention, the detector is preferably a high resolution detector, i.e., at a size of 35 mm x 35 mm it has approximately 1000 x 1000 pixels. Because of its high resolution, the detector can be arranged directly under the board assembly at a distance not exceeding approximately 5 cm. Thus, the diameter of the X-ray beam contacting the test object is only enlarged to a limited degree. Because of the high resolution of the detector, however, the accuracy of the inspection is not impaired by this. By using this special detector, the device according to the invention can be constructed even more compactly.

Because of this construction, it is not necessary for the X-ray beam source to emit an X-ray beam with only a small focal spot diameter. According to the invention, microfocus tubes with a focal spot diameter of approximately 20 μm to 40 μm produce a satisfactory image sharpness. The use of X-ray beam tubes with enlarged focal spot diameters is advantageous because such an X-ray beam tube emits more photons and thus allows for a better S/N ratio and a better image quality.

According to the present invention, the X-ray tube itself and the high-voltage element that contains the power supply for providing the X-ray acceleration voltage, which typically lies in a range from approx. 10 to 100 kV, are moved during the movement of the X-ray source while the control device for changing the operating voltage or the output is housed in the control box so as to be immovable.

Because the X-ray beam tube and the detector, which are the same components

in each measurement, are moved, the adaptation of the movement components for the X-ray beam tube and the detector has to be performed once. The adaptation takes place according to known calibration processes. Ins B5

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention is described in greater detail in the following with reference to the accompanying drawings.

Fig. 1 shows a schematic view of the device according to the invention for explaining the principle of the ~~invention~~ invention;

Fig. 2 shows the use of the device according to the invention for recording oblique projections applied to the three-dimensional evaluation of the test objects.

DETAILED DESCRIPTION OF THE PRESENT INVENTION

Fig. 1 shows a schematic view of a first embodiment of the present invention. In Fig. 1, reference number 1 refers to an X-ray beam tube, reference number 2 refers to an X-ray beam detector, reference number 3 refers to a board assembly to be examined that is loaded with components 4. The X-ray beam tube is mounted in a moveable housing and can be moved in the X and Y directions.

The device shown in Fig. 1 is used as an example of a completely automated 100% X-ray inspection of soldered joints on printed circuit boards as well as on printed joint assemblies.

The board assembly 3 is secured to a housing and is moved into the examination chamber sufficiently slowly that the forces acting during this process do not cause any damage to the soldered joints. Then the board assembly 3 is fixedly positioned (i.e., stationarily) ~~positioned stationarily~~ so that it is not moved ~~any more~~ during the soldered joint inspection. For recording any section of the board assembly in the area to be examined, the X-ray beam tube 1 and the detector 2 are moved parallel to one another in the X and Y directions. The detector unit 2 includes a camera system that is not shown here. During the examination process, the corresponding area of the board assembly 3 is illuminated by X-ray beams and the

absorbed X-ray beams are converted to visible light by the detector. With the aid of a camera system, the X-ray image is recorded and transmitted to a computing device for evaluation.

INS C1 At the beginning of the soldered joint examination, the loading data of the board assembly are retrieved. The loading data (CAD data) define which component is placed at which position and at what angle of rotation. On the basis of this information and taking into consideration the object resolution, it is possible for each recorded X-ray image to determine precisely where a soldered joint of a component is shown in the X-ray image.

In the computing device, with the aid of the underlying CAD data, the soldered joints appearing in the image are "cut out" and subsequently transmitted to the image analysis unit.

Depending on the loading density of a board assembly, some thousand soldered joints are located on each panel of a board assembly. Theoretically, the technician who compiles the examination program for this component would have to assign testing parameters to each soldered joint. This interactive input is not only time-consuming but also very susceptible to error. In particular, it is very difficult to find the correct adjustments (tolerance, threshold, etc.) that guarantee a minimal occurrence of pseudo-slippage. Therefore, according to a preferred embodiment of the present invention, the system is programmed in such a way that it finds the parameter itself, which saves a significant amount of time and requires no interaction on the part of the user. In this embodiment, the threshold/tolerance determination is very close to reality and is only improved in a few places by the user.

Thus, according to this preferred embodiment, two modes are available for the subsequent image evaluation for inspection of soldered joints.

Learning Mode

A set of testing algorithms to be used is transferred to the image analysis unit by ~~means of~~ the image buffer. With the aid of these algorithms, a characteristic vector is generated for the individual soldered joint. This characteristic vector describes only this soldered joint and no other soldered joints of the same type. This characteristic vector is optimized with the vectors of the same soldered joint of further boards so that, in an ideal situation, after several defect-free soldered joints have been examined, a characteristic vector has been generated that statistically represents a defect-free soldered joint. This characteristic vector can be stored in a testing database by pad and components, so that the learning process can be omitted with new boards to be tested that contain components of the same type. These vectors are also stored in the component-specific board assembly data file.

Testing Mode

In the testing mode, the image evaluation unit of the pad image buffer, the set of testing algorithms, and the learned characteristic vectors are transmitted with permissible variations.

When the characteristic vector obtained correlates with the learned vector within the predetermined tolerances, the soldered joint is classified as defect-free, otherwise it is classified as defective.

Here, the set of testing algorithms is not provided in a fixed manner and it need not be limited with respect to components. The user can also freely add new algorithms into the system and incorporate them in or exclude them from inspections as needed.

The following defects can be localized in the board assemblied by the testing process used. On the one hand, a faulty soldering quality such as, for example, cavities, blow-outs, sunken spots, poor and/or no wetting of components, lack of contact on the

component, too much or too little solder, solder bridges (short circuit), tin nodules and other tin residue (e.g., between conductors or connections) and, on the other hand, defective loading quality, such as, for example, a missing component, a component that is warped or displaced, a component placed too high, leads bent or displaced. The types of components that can be examined are THT (Through Hole Technology), SMD (Surface Mounted Devices), and BGA (Ball Grid Array).

In order to record another section of the board assembly in the area to be examined, the X-ray beam tube 1 and the detector 2 are again moved parallel to one another in the X and Y directions while the board assembly remains stationary. These processes are conducted until the entire section of the board assembly 3 to be tested has been examined. The position recognition of the individual sections of the board assembly

B is effected by ~~means of~~ an automatic evaluation of the positions of pass marks and/or plated-through holes.

In the device according to the invention, it is also possible to move the X-ray beam tube 1 and the X-ray beam detector 2 in opposite directions from one another in order to cause a diagonal penetration as shown in Fig. 2. Thus, cross-sectional images can be made that are suitable for three-dimensional layer image recording in the framework of a tomosynthesis process. The distance measurements necessary for the tomosynthesis

B process preferably are performed by ~~means of~~ a laser triangulator.

Because the board assembly is not moved during the examination process, component-specific weights do not have any effect in the form of up-and-down vibrations of the board assembly. Thus, on the one hand, no waiting times for cessation of vibrations are necessary and, on the other hand, distance measurements to the surface of the board assembly are conducted with increased accuracy. This increased accuracy of the distance measurements has an especially advantageous effect in the three-dimensional tomosynthesis process.

After the end of the examination process, the board assembly 3 is removed from

the examination chamber sufficiently slowly that the forces acting during the process do not cause any damage to the soldered joints.

According to the present invention, an additional mechanism can be provided for moving the detector in the Z direction (parallel to the surface normal of the assembly). Thus, a component-specific adaptation of the object resolution can be achieved. This leads to an optimization of the attainable examination speed in two-dimensional as well as three-dimensional inspection because, for example, assemblies and components with a coarser soldered joint structure can be examined with a correspondingly higher surface throughput.